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A GENERAL THEORY OF SENSATION AND OF NERVOUS ACTIVITY.

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It is strange that up to the present time no general theory of sensation has been advanced which has found any degree of acceptance. There are theories in plenty as to the causation of color vision and of pitch perception, but none as to the common nature of the causation of sensation in all its varied forms.

There are also different theories as to the nature of the nerve impulse, which is but a fraction of the whole nervous act, viz., that portion taking place in the axis cylinder; but a careful examination of text-books and archives reveals no trace of an hypothesis as to anything in common in the character of all forms of nervous activity.

It is indeed surprising that so little attention has been paid to the similarity of the whole nervous process. It has been taken for granted that the nerve impulse is always the same in character, and various speculations have been indulged in as to its nature, but it seems generally to have been forgotten, or at least left unmentioned, that the inception of the nerve impuse in the end organ must also be a process of a common type in all the varied sensations.

Further, an afferent nerve impulse starting from a nerve cell must probably be originated in an identical or closely similar fashion in all cases, no matter where the nerve cell is situated or what form of activity the impulse may awaken when it arrives at the other end of the axis cylinder process.

Again, it is most probable, if the nerve impulse is always the same in its nature, that when an efferent nerve impulse arrives at a peripheral cell it always stimulates the cell's activity in much the same fashion, though of course this activity varies in its results with the nature of the peripheral cell which is stimulated. The view that all forms of nervous activity have much in common, and that all are started and terminate in a similar fashion, gains much support both from teleological and morphological considerations.

A study of the evolution of the nervous system clearly shows that all sensations of different types must have arisen from one fundamental sensation by the adaptation of special peripheral end organs to receive more favorably than other end organs in other parts of the periphery specific disturbances in the external world. These particular end organs being connected with nerve cells in definite locations in the central nervous system, always stimulated definite and specific parts of the central nervous system. This location is of itself sufficient to explain the differentiation of sensations of different kinds without any supposition that the manner in which the nerve impulse is started at the peripheral organ is different in each individual case, or that the process of excitation of the central nerve cell is different.

Take, for example, the case of the special senses. The type of sensation evoked by an afferent impulse will depend purely on the location of the cortical cell reached and not on any difference in the nature of the nerve impulse reaching it, nor upon any difference in the manner in which that impulse was evoked. The law of specific sensation demonstrates this as well as the effects of cortical stimulation in different areas.

The manner in which an afferent impulse originates at the periphery is also in all probability closely similar if not identical in the different cases. The end organ is indeed so altered in structure that it only responds to certain forms of stimulation, in the eye, for example, to light waves and in the ear to sound waves. But there is no reason to believe that there is any alteration in the manner in which the peripheral cell when once excited passes the excitation on to the terminal ramifications of the nerve fibre. In fact, similarity of histological structure in many cases supports the view that the process is of a very similar type. Consider in this relationship the structure of the end organ in the case of the visual, auditory, olfactory and gustatory sensations. In all four cases, the cells first excited by the external stimulus are of a common type; in no case does the nerve fibre communicate with this cell, but in all it arborizes around it in a similar fashion. These facts go towards showing that although the structure of the end organ is somewhat changed to suit the nature of the external stimulus which it is designed to receive, yet the mode of transference once the peripheral cell is excited is probably much the same in all four cases.

In like manner, attention may be drawn to the fact that the nerve cells of different portions of the central nervous system are placed in physiological communication with one another, by very

similar systems of arborization, pointing to a like mode of action throughout the entire central system. If resemblances in the manner of excitation of certain of the end organs be next examined, it will be found not only that the probability as to a common kind of activity is increased, but further, that important conceptions suggest themselves as to the characteristics of the phenomenon.

In both auditory and visual sensations the excitation is produced by energy in a vibrational or periodic form; in both cases there is a minimum and maximum limit of frequency between which the rate of the vibration must lie in order to produce an effect, and in both these forms of sensation the quality of the sensation produced depends directly upon the frequency of the vibration.

These facts strongly suggest not only that the nature of the excitatory process is the same in both cases, but that the rate of vibration is in some way translated to the columnar cell of the end organ and alters the character of its excitation so as to give rise with different vibration periods to different color sensations or to different pitch sensations. The simplest supposition to make is that the excitation of the peripheral cell is also rhythmic and follows the rate of the vibration which has excited it.

There is no structural difference in the rods and cones or in the cells of the organ of Corti which can lend support to the view that one of these cells responds to a vibration of one period while another close by answers to a vibration of a different period. On the other hand, everything favors the view that each cell is capable of being stimulated by any vibration lying within the limits of frequency to which the organ as a whole is adapted. Further, when the peripheral cell does so respond to stimulation, the result produced in the cerebrum varies with the vibration rate used in exciting the cell.

When the results obtained by stimulating the auditory or visual end organs are contrasted with those obtained on tetanizing a skeletal muscle by electrical stimuli of varying periodicity, it will be found that a wonderful degree of similarity exists between the two sets of physiological phenomena, although they appear at first sight to be so vastly dissimilar.

If a single stimulus be applied to a muscle either directly or through its nerve, it replies by a simple twitch and then returns to a relaxed condition; if a series of stimuli be applied at a slow rate, a corresponding series of twitches is obtained separated by intervals of quiescence. If, now, the stimuli succeed one another so rapidly that the contraction caused by one stimulus has not time to

pass off before the succeeding stimulus is thrown in, the muscle remains all the time partially contracted, so giving rise to *incomplete* tetanus, while at each stimulus the amount of contraction is increased, causing a flickering contraction. If the rate of stimulation be increased still further the muscle passes into *complete* tetanus and remains permanently contracted (i. e. excited) during the entire period, without any flickering in the degree of contraction. This condition of affairs persists if the rate of stimulation be further increased through a wide range of frequency, but finally a maximum rate is reached beyond which the muscle will no longer respond to stimulation and remains quiescent and uncontracted. It is well known, for example, that with a rapidly alternating current possessing a frequency lying between 10,000 and 20,000 alterations per second, the human body may be used as a conductor through which electric lamps may be illuminated, and yet the muscles do not show even by a single twitch that the rapidly alternating current is passing through them and their attached nerves.

Although complete tetanus is obtained with all rates between 30 per second and the maximum rate at which stimulation begins to fail to produce a physiological effect, and as far as a myograph tracing goes there is nothing to show a difference in the contraction obtained, yet there is nevertheless evidence to show that the rate of tetanization is impressed upon the muscle, and that each stimulation in the rapid rates produces a physiological effect and goes towards the maintenance of the tetanic condition. This is shown by the agreement in pitch of the note obtained in a telephone receiver connected with the tetanized muscle with that given by the alternating current used in stimulating the muscles.

This view that no effect is obtained with high frequency alternations, because the rate is above that at which muscle by its structure is able to respond, is so far as I know a new one, and seems to me more feasible than the usual physical hypothesis that such high frequency currents are carried by the skin, or that a direct or low frequency current has a different distribution in the body, whereby it does not spread uniformly and so vitally injures certain organs.[1] It has been suggested to me by the leading idea of this paper that all nervous activity, and indeed all protoplasmic activity, is of a common type, and is rhythmic in its character and mode of incep-

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[1] See N. Tesla's Inventions, Researches and Writings, edited by J. P. Martin, New York, 1894, p. 320.

tion. According to this view, the muscle is quiescent at the higher rates of stimulation for the same reason that the excitable structures of the retina are not stimulated by the ultra violet rays, or that corresponding structures in the organ of Corti remain unaffected by aerial vibrations which possess a frequency above the limit of audition.

Further examination brings out additional analogies between muscle excitation and the stimulation of the peripheral structures of the special sense organs. Let us first compare auditory stimulation with that of a skeletal muscle. As the rate of the auditory stimulation is increased there is first a period at which the vibrations of the air are felt discretely corresponding to the separate twitches in the case of the muscle; later there is a period at which the separate waves fuse partially and give rise to a tremulous or flickering note, such as that obtained with the 32 foot organ pipe, this corresponds to incomplete tetanus in the muscle; next a frequency is reached which causes the individual vibrations to become completely fused so giving rise to a steady and perfectly continuous note, this corresponds to the stage of complete tetanus in muscle stimulation; finally, if the rate of stimulation be now many times increased a maximum is reached at which the peripheral auditory organ ceases to respond, and this corresponds to that frequency of stimulation at which the muscle ceases to contract.

In the case of visual sensations, the parallel is perhaps not quite complete, because the visual sensation is not awakened by slow rates of stimulation. The peripheral end organs of vision do not begin to be excited until the rate of vibration has reached hundreds of millions per second, and hence what corresponds in the analogy to complete tetanus is the first result obtained, and the quality of sensation evoked merely changes with the rate of stimulation until the maximum limit is reached with the rate corresponding to the violet rays, then the effect ceases and no visual sensation is provoked by the ultra violet rays, although these do not differ in kind from the violet rays save only in frequency of vibration. Even here, then, we have a maximum frequency up to which the peripheral end organ can follow and respond and beyond which it remains quiescent, and a change in sensation as the rate is altered of which the easiest explanation is that the rhythm of the stimulus is impressed upon the end organ. Further, if we consider the effects of rhythmically interrupting visual stimuli, we find results which show an analogy to incomplete tetanus in muscle and to the tremulous sensation of very deep bass notes in the auditory sensa-

tions. If the retina be illuminated intermittently by a light which is cut off at regular intervals of time, it is found that when the rate of extinction is made less than about ten times per second the illuminations are appreciated as separate flashes, while if the frequency of interruption be greater than this rate a continuous but flickering sensation is obtained analogous to incomplete muscular tetanus. At a still higher rate which varies with the intensity of the illumination and other circumstances, the sensation of a flickering illumination is replaced by one of a steady illumination.[2] The cause of this after duration of visual sensation, on the theory outlined in this paper, would be that a certain short interval of time is necessary for the excitable structures of the retina to recover from the state of vibrational excitation invoked by the light waves. If excitation be renewed before complete recovery has taken place, then the result will be the flickering sensation; if excitation afresh take place before any appreciable relaxation from the excited condition has had time to appear, then the result will be a steady sensation in spite of the rapidly repeated interruptions of stimulation. A similar explanation can be applied to after sensation in the case of the other senses.

Although the rhythmic stimulation of the peripheral cells in the special sense organs which has here been postulated need not necessarily so closely resemble in outer physical appearance a muscular tetanus as to involve a change in shape and shortening in length of these cells, still it is interesting in this connection to draw attention to the fact that actual shortening of the cones in the retina has been observed by Engelmann as a result of stimulation of the retina by light waves, and although such experimental observations are exceedingly difficult, it may yet be shown that similar alterations in form take place in the case of the other peripheral end organs.

It scarcely requires pointing out that this after duration of sensation is closely analogous to the period of relaxation or recovery occurring after tetanization in a muscle. The period of relaxation is more prolonged if the muscle is fatigued, so also in the case of the retina, the duration of the after sensation is increased when the retina has been fatigued by exposure to light. Further, the relaxa-

[2] The rate for this is usually stated to lie between 50 and 100 illuminations per second; for the suddenness with which the light is turned on and off the retina, as well as the brilliancy of and the colors of the light and the degree of fatigue of the retina, appreciably after the rate at which flickering disappears.

tion of the muscle takes place more sharply if the tetanus has been produced by a strong stimulus, and similarly the optical after sensation fades off more rapidly with a brilliant illumination, so that a more rapid rate must be employed in order to give rise to a uniform sensation.

The genesis of tetanus by alteration in the frequency of stimulation is usually shown in the laboratory by using a spring of alterable length carrying upon its end a needle placed at right angles to its length, which dips into and out of a cup of mercury as the spring vibrates, so making and breaking the primary circuit and stimulating the nerve muscle preparation at a corresponding rate, the spring being kept in vibration by a small electro-magnet which is placed in the primary circuit and made and broken at a corresponding rate. Now, if while one experiments upon a *perfectly fresh* muscle preparation, one also takes note of the fusion of one's own sensations of special sense by watching the sparking as contact is made and broken at the mercury contact, listening to the sound caused by the sparking and at the same time touching the upper end of the pin in the vibrating spring, one easily can appreciate that the rate of fusion is a thing of the same order of magnitude in all four cases. The same rate which causes a complete tetanus, causes the sparking to become almost completely continuous and the noise of make and break a continuous rattle, while the tactile sensations also fuse into a continuous sense of vibration or tickling.

It is commonly stated in text-books of physiology and psychology that complete fusion of tactile sensations is difficult to obtain, and this view is based upon the experimental observations that a body can be distinctly felt as vibrating and different from a body at rest, when it is vibrating at a rate of several thousand times per second, and also that an induced current vibrating from 5,000 to 10,000 times per second can be distinctly felt when applied to the tip of the tongue.

Now, such a view as to the complete fusion of tactile sensations appears to me to be based upon a misconception as to the period at which complete fusion takes place, namely, that complete fusion into a continuous and steady sensation has not taken place until the vibrating body gives an identical sensation with a body at rest.

In the opinion of the writer, when a body vibrates at such a rate that it causes the same tactile impressions as a body at rest, the limit which has been reached is not that at which tactile sensations completely fuse to continuous sensation, but instead the limit at which tactile sensations cease to excite the tactile end organs, that is to say, a limit analogous in tactile sensation to ultra

violet in visual sensation, to ultra-audible in auditory sensation, or to the limit at which muscle no longer responds by contraction.

When the speed of vibration reaches the point at which all tactile sensation of vibration is completely lost, then our tactile sensations obtained by contact with the body are due in no sense to the rapid vibrations, but to other causes which would be still present, if the body were at rest, and if these latter stimuli could be completely removed, we would have in all probability no tactile sensations due to the contact with the rapidly vibrating body whatever. Hence the speed of vibration at which the body feels like a body at rest is not the point of complete fusion of tactile sensation, but the point at which tactile sensations fail because of rapidity of stimulation.

The point at which fusion of tactile sensations take place is readily appreciated by anyone who carries out the simple experiment with a slowly vibrating spring mentioned above; with a stimulation of four to five times per second each tap of the needle upon the end of the finger is distinctly felt, but when the rate is increased to thirty to forty times per second a continuous tickling sensation is the result obtained. The view combatted here that the tactile sensations are not completely fused, is undoubtedly due to an incorporation of our knowledge that the sensation is caused by a vibrating body which touches intermittently and not to any discontinuity in the sensation itself. Because we know that the sensation is due to an intermittent stimulation, we falsely judge that the sensation is also intermittent.

If the manner in which tactile sensations are obtained from contact with a resting body be next considered, it will be seen that the view stated above gains further support.

It is a general law that all stimulation is the result of change, and that a stationary condition gives rise to quiescence, a fact which in passing may be pointed out as supporting the views put forward in this paper as to the nature of nervous excitation. A well known illustration of this law is found in the fact that an electrical current, once it has been established in a nerve, gives rise to no stimulation. The law is also exemplified in tactile sensations, for it is only a variation in pressure which awakens the peripheral endings of the tactile nerve fibres to activity and not a steady pressure, however great. This is shown in the common experiment of dipping the fingers or hand into a vessel of mercury at or about the same temperature as that of the body. The strong tactile sensation of contact with the skin is only felt at the ring at which the skin touches the surface of the mercury, while all the parts deeper down in the

mercury scarcely give any tactile sensations whatever. This clearly demonstrates that it is not the amount of pressure which furnishes the stimulus for tactile sensations, but rather the variation in pressure from instant to instant compared to the total mean pressure. For, if the tactile sensations were caused by pressure and proportional to the pressure, those parts immersed most deeply in the mercury would be most strongly affected. On the contrary, it is the area just covered by mercury which has the tactile endings most strongly stimulated, and the obvious reason is that here the pressure is varying most from instant to instant as slight involuntary movements and tremors cause more or less of the finger or hand to become immersed. Similar alterations, of course, occur at deeper levels, but here the variation forms a smaller percentage of the total pressure and hence exerts an inappreciable stimulus.

That tactile stimuli are caused by vibrations in pressure may also easily be demonstrated by the following simple experiment. Place the forefinger palmar surface upwards at rest on a thin board which can easily be caused to vibrate by tapping it. Next instruct another person to lay a light object, such as a pen or pencil, across the finger, with one end resting on the board or table. The contact of the light object with the finger is easily felt as it is applied, but after a time it is scarcely felt or uncertainly felt, if the finger be kept as still as possible; but if now the person assisting taps the table so as to make a vibration in pressure, or, if the finger be wriggled, the touching object is felt most distinctly. The experiment exceeds less perfectly with a heavier object, and for this reason that the volume of the finger itself is oscillating all the time with each pulse beat, etc., and with a firm contact these sources become sufficient to give variations. It is probable that it is by such fluctuations in pressure that tactile sensations are produced when the finger is held firmly against a solid body at rest. Here there are, in addition to other causes of variation in pressure, the vibrations at the rate of ten to fifteen per second caused by the incomplete muscular tetanus of volitional contraction, and just as we are unaware of any tremor of the muscles even at this low rate of tetanus when we press tightly against a resting object, so we are equally unaware of any vibration in the tactile sensations, although it is most probable that these are rhythmically stimulated by variations in pressure occurring at the same rate as the muscular contractions.

It may be concluded, then, that where from great speed of vibration the vibrations can no longer be appreciated by the tactile sensation, that the maximum limit has been passed and that the

simple sensation of constant contact with a body at rest is then evoked by the slower vibrations described above and not by the rapid vibrations.[3]

The tactile sense does not differ, then, on the above showing, appreciably in its period of after duration of sensation from auditory or visual sensations, and if it be granted that I have proved this, it may be pointed out in support of the general vibratory theory of sensation that by suggesting completeness of analogy it has led me to the view above expressed.

The theory that different rates of vibration give rise to qualitative differences in sensation, also furnishes, in the case of the sensations of taste and smell, an easy explanation for the differences in sensation which there exist.

Just as different rates of vibration being impressed upon the peripheral end organs of vision and hearing give rise to differences in color and pitch, so different rates of vibration being impressed upon the peripheral organs of taste and smell occasion varied sensations in these two special senses.

In support of this may be mentioned the view universally held by chemists that the molecules of gases and dissolved substances are in a constant state of vibration, and also that the constituent atoms and radicals in a complex molecule have vibration rates with regard to the molecule as a whole. Further, the rate of vibration is specific for each molecular group, and accordingly varies for different groups in such a way that there is an infinite series of rates of vibration. If it be supposed that these rates, or rates proportional to them, be communicated in the act of stimulation to the peripheral cells of the organ of taste or smell, an explanation of the different taste and smell sensations is developed which shows an interesting analogy with the mode of origin of the visual and auditory sensations. Just as there are vibration rates which are either too slow or too fast to set in sympathetic vibration and so excite the peripheral cells of the retina, so there are molecular vibration rates which do not lie within the suitable range to excite the olfactory or gustatory cells, and the chemical substances possessing these rates of vibration are accordingly odorless or tasteless. Those possessing vibration frequencies lying within the range of sensi-

[3] The limit at which vibrations fail to cause tactile sensations lies above 10,000 and lower than 20,000 per second, as is, I believe, shown by the experiment, that a magnet which is magnetised and demagnetised over 10,000 times per second appears to the touch to continuously and constantly pull upon a piece of soft iron held near it. See J. C. Martin, in Tesla's Inventions, Researches, and Writings, p. 124.

bility will possess on the other hand odor or taste, and the quality of either sensation will depend upon the position in which the rate of vibration lies in the range of active rates. It is interesting in this relationship to point out that similarity in chemical constitution giving rise to molecular groups vibrating at similar rates causes similarity in odor or taste. Thus, nearly all inorganic salts of the alkalies have very similar saline tastes, and their molecules must have very similar rates of vibration; again, inorganic acids have a common type of acid taste, all the group of the sugars have sweet tastes, and all the cinchona alkaloids possess a bitter taste. A similar correlation in the smell of bodies may also be made out related to their chemical composition and to the occurrence in them of identical or closely allied organic radicals, as examples may be mentioned substituted ammonias, mercaptans, and isocyanides. In such cases, the molecular vibrations must possess similar vibration periods. and this furnishes the easiest explanation of their similarity of physiological action upon the olfactory and gustatory nerve endings.

So far regard has only been paid to the effects produced by a simple vibration of a single period, and to the results of altering the periodicity upon the quality of the sensation, and no consideration has been given to the possible effects produced by *simultaneous* stimulation of any peripheral cell of special sense by two or more vibrations of different period. Here the study of the resultant sensation becomes very much more complicated, and especially so in connection with visual sensations where one comes in contact with the many phenomena of color vision. The subject gains in simplicity, however, if all those special theories of color vision which do not apply to the other senses and are moreover exceedingly artificial and incredible in themselves be completely cast aside, and the whole matter looked at from a common standpoint by drawing as many analogies as possible between the different senses under like conditions.

The subject is perhaps best approached by considering the evolution and development of a sensation, and trying to discern what there may be in common about the manner and degree of development of qualitative differences in sensation in the case of the various senses, remembering always that there must be in the different senses a difference in extent of development.

The first thing that would naturally arise in the development of a new sense would simply be excitability of a common type to a specialized form of stimulation or vibration, without the presence of any qualitative appreciation of difference due to rate of vibration.

For example, the end organ in the eye would be stimulated by all rays having a frequency within a given range; there might be a difference in *intensity* of stimulation with the same amplitude of vibration within that range, probably the rays in the middle of the active range would be more powerful than those towards either limit,[4] and also the length of the range would increase in time, but there would as yet be no differentiation of sensation of a *qualitative* nature between the rays lying within the range, but of different frequency. An animal in such a stage of development, or an individual in such a stage of development, for it is probable that the young animal must pass through all the stages in the development of its organs of special sense, would simply see the external world in white and black, in light and shade from which all color was absent. Similarly it would be with other senses; there would be sound of varying intensity, or silence, but no qualitative difference in various sounds due to difference in pitch; a substance would taste or be tasteless, but there would be no difference save in intensity between tastes, and similarly with olfactory sensations.

Later on a differentiation of the effects produced in each case by variation in rate of stimulation would *gradually* arise, at first the developing sense organ would only help to differentiate between frequencies widely apart, and those near together would be indistinguishable from one another. At first, possibly only two varieties of sensation would begin to be differentiated, namely, between the lower frequencies of the range and the higher, while the intermediate frequencies would have a quasi differentiation as a neutral sensation.

Still later a small number of sensations would arise, of which those farther apart would be most distinctly differentiated. In this position with regard to development are at present most of our sense organs, and while we are able in frequencies near together (such as the various wave lengths of red for example) to differentiate shades of difference, yet we recognize that all those rates lying within a certain range produce sensations which are very closely akin. Accordingly we find but a limited number of colors, tastes, smells and degrees of pitch.

In this respect, auditory sensation seems to be most developed, the range of activity is longer and there is a recurrence to the same type observable when the rate of vibration is doubled (as in the

[4] A peristence of this is seen in the fact that the yellow rays of the middle of the visual range are much more effective than either the red or violet rays.

octave relationship) so that the play of qualitative change is confined to a small fraction of the entire range and repeats itself at regular intervals. This merely means that the auditory sense is somewhat more developed than the others.

In the visible spectrum we conventionally name seven colors, but it is obvious that certain of these lying close together do not give rise to distinct sensations, but to sensations which are in part the same as those of a higher frequency, and in part the same as those of a lower frequency. In time these partially differentiated sensations will undoubtedly become more distinct, thus leading to an increase in the number of our color sensations.

In taste as in color we find but a small amount of differentiation into distinctly different types of sensation.

Next, let us consider the effect of the superposition of two or more vibration frequencies of different rate upon the same peripheral cell of an organ of special sense, remembering that the differentiation of sensation as a result of change in frequency of excitation has only developed to the partial extent indicated above. The cell may obviously take up separately the two rates of vibration and transmit them along the nerve fibre to the sensorium independently, where, depending upon the degree of development, they may or may not be appreciated as distinct effects, or the two rates of vibration may be fused, giving rise to a single sensation which is in its properties a mean of the separate sensations called out by the two rates of vibration.

A discrete appreciation in the form of separate sensations will be favored by the increased development of the particular sense concerned, or by distance apart in the rate of vibration. Thus, sound vibrations of different period more easily produce discrete sensations than do light waves of different period, and again, we can more easily make out both red and blue in purple, than red and yellow in orange or red and green in yellow.

The fact that white, or rather a gray, can be produced by simultaneous excitation with two or three appropriately chosen colors shows this fact, that the visual apparatus is not sufficiently highly developed to pick out and analyse the compound vibration by which it is stimulated. White is the greatest complex which can affect the retina, and when vibrations with a comparatively small number of the vibration rates, situated at appropriate portions of the range, are allowed to fall with properly balanced intensities upon the retina simultaneously, the mixture in the present stage of development of the visual sense produces the same effect as far as

sensation is concerned as the still more complex white itself. For a like reason any two vibration rates will give rise to a sensation lying intermediate between them instead of being separately appreciated. Even in the case of auditory sensation, however, the number of notes of different pitch within an octave which can be recognized as distinct is very limited, varying with the individual, but usually limited to three. Here again more than a few notes in the same octave gives rise to a noise in which the number and pitch of notes cannot be distinguished. White in color is what noise is in music, a number of vibration frequencies indiscriminately thrown together, but since the visual sense is not so much developed, a fewer number of different frequencies is sufficient to cause the same effect and produce a white or gray. Similarly in gustatory and olfactory sensations, there is fusion of effect when two vibration frequencies of different rate are thrown in together. Take for example the neutralizing effect of sugars upon organic acid tastes. It is interesting here to note that practice is capable of altering the discriminating power, as is well shown in the training of the ear in music, and also in the training of the nose in testing mixed perfumes, where connoisseurs can pick out and name three or four odors at once, while the ordinary person obtains simply one blended sensation. The same fact is shown in the acquired appreciation of bouquet in wines or of aroma in cigars.

Individual development and heredity also plays a large part in the differentiation of sensations. One person has no musical ear, can scarcely appreciate any difference in pitch, and cannot tell whether two notes are struck at the same time or only one; another cannot appreciate any color sensations, or has a smaller sense of discrimination of color than his neighbors, so that colors which are different to them look alike to him; still another has either no sense of smell, or can only detect certain smells and fails to be affected by others, or thinks two odors alike that are distinctly different to the normal person. All these defects of sensation are of a common type, and it is unwise scientifically to set defective color vision apart and consider it as different from examples of defective development in any of the other senses. All these defects arise as a result of incomplete development of power of differentiation of sensation in one or other sense organ, and represent a recurrence to that more rudimentary condition of the organ in which appreciation of different rates of stimulation was less perfect than it is at present in the normal individual.